The SoilSCAPE in-situ soil moisture network: innovations in network design and approaches to upscaling in support of SMAP

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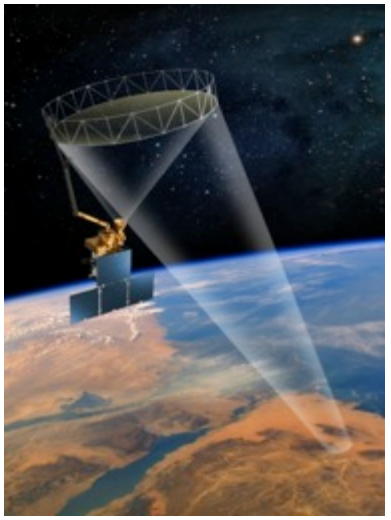
Soil Moisture Active and Passive (SMAP) Mission

Primary Science Objectives:

- Global high-resolution mapping of soil moisture and its freeze-thaw state to:
  - Link terrestrial water, energy, and carbon cycle processes
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Extend weather and climate forecast skill
  - Develop improved flood and drought prediction capability



Mission Approach:

- GSFC L-band radiometer
- JPL L-band radar
- Common 6m rotating antenna for 3-day global repeat coverage
- Merged radar and radiometer data for high-accuracy, mid-resolution, soil moisture
- 670 km polar sun-sync

Development Status:

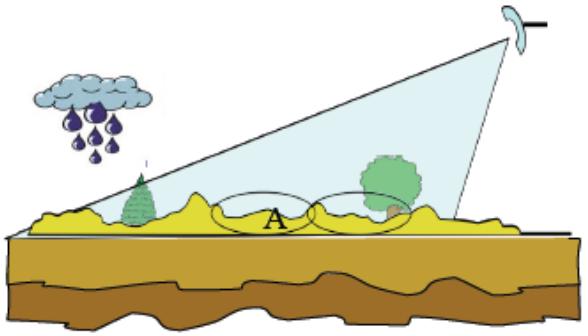
- Launched successfully, January 2015
- On-orbit checkout: completed
- Cal/Val phase: ongoing
- Beta release of Level 1 data: July 2015
- Beta release of Level 2 products: Oct 2015
- Several algorithms and cal/val workshops held
- Science Team selected in 2013; 5 meetings held so far

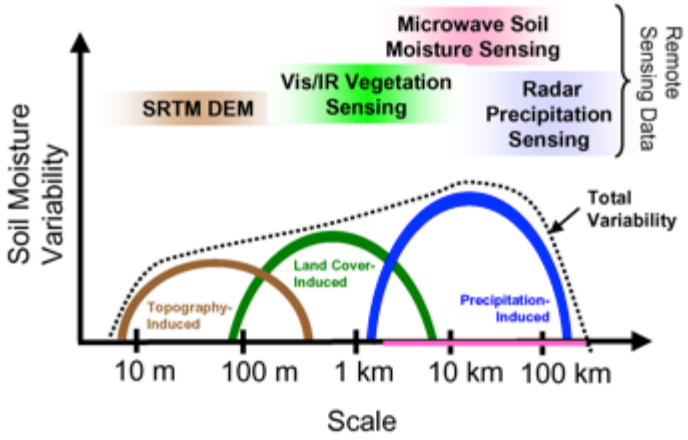
Cal/val plan:

- Takes advantage of several cal/val “partners”
- validation partners chosen in response to “dear colleague letter”
- Number of cal/val sites is ~20
- “Core” validation sites must meet spatial sampling criteria, data quality requirements, scaling function, and have easy & rapid data access
- SoilSCAPE is a cal/val site for SMAP, on-course to become a core validation site

Background and Objectives (1)

Soil moisture Sensing Controller And oPtimal Estimator (SoilSCAPE)





develop technologies for near real-time validation of spaceborne soil moisture estimates from the Soil Moisture Active and Passive (SMAP) mission.

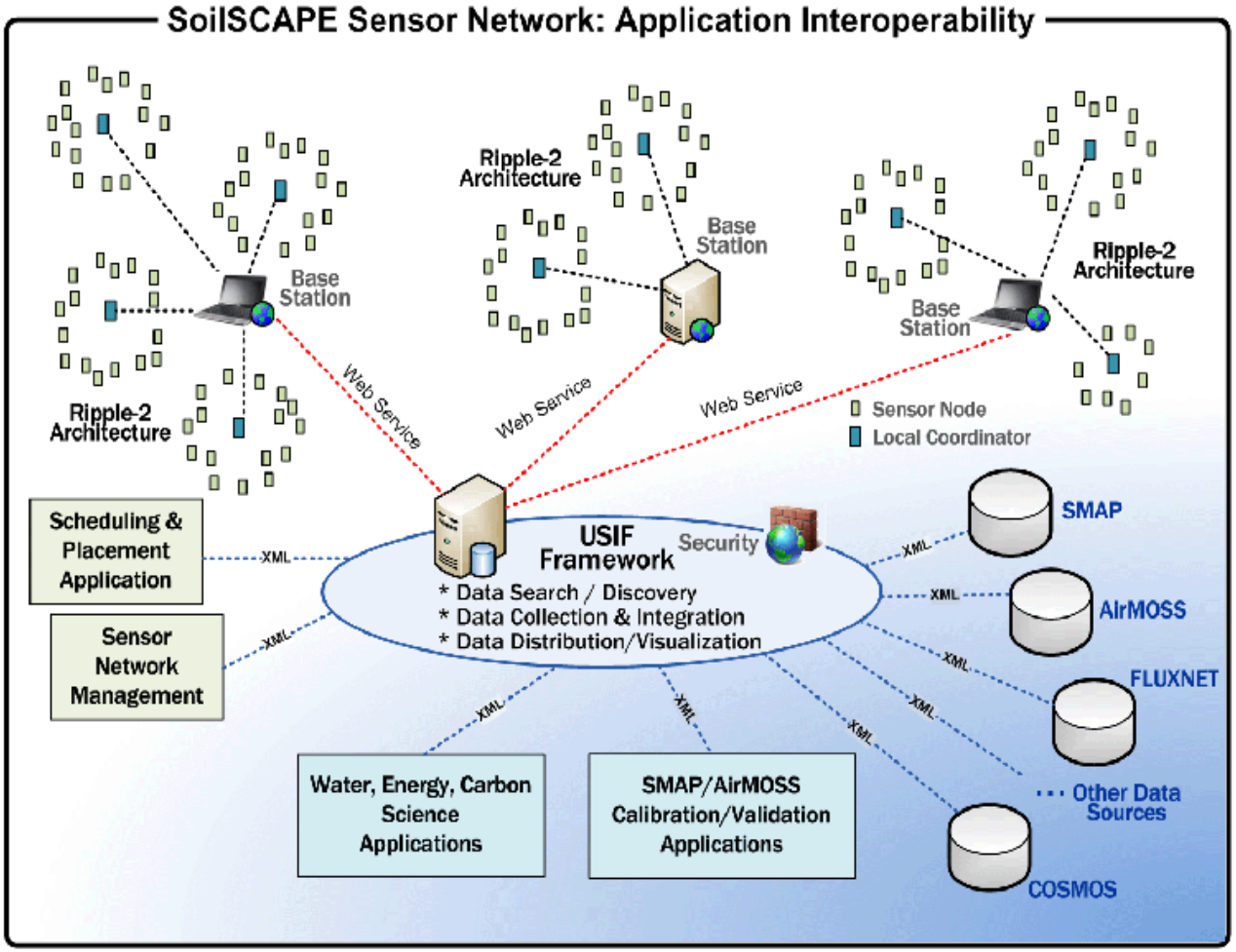
Soil moisture varies on spatial scales of meters to tens of kilometers, and temporal scales of minutes to days.

SMAP radar and radiometer will each observe soil moisture, but with different spatial resolutions. Both capture lots of landscape heterogeneity due to large pixel sizes.

Validation of these multi-scale measurements requires adaptive temporal and spatial sampling strategies.

Background and Objectives (2)

Generalized SoilSCAPE Framework



Background and Objectives (3)

Specific Objectives are to develop:

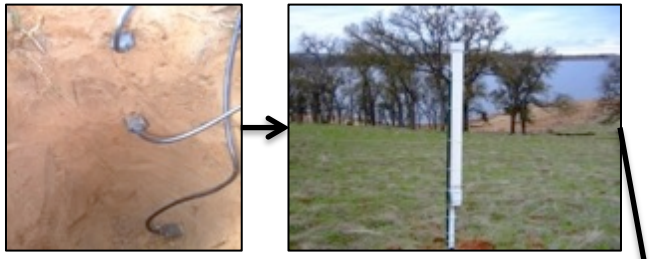
- Generalized SoilSCAPE Framework:
  - Flexible energy management to meet mission lifetime requirements
  - Increased network reliability and reduced costs
  - Extensible network architecture
  - Energy-efficient nodes and devices
  - Adaptive scheduling of sensor nodes to maximize longevity
  - Accurate soil moisture process estimation techniques including accounting for faulty sensors

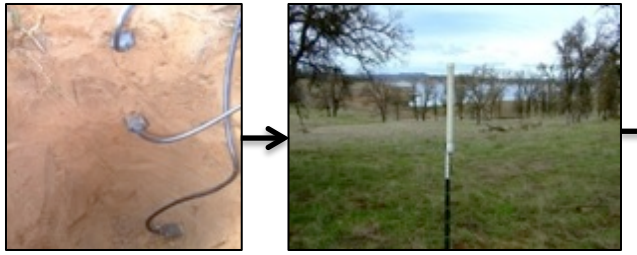
- Unified Science Information System Framework:
  - Distributed Search/Discovery
  - Data Collection & Integration
  - Data Dissemination for science support (visualization and analysis)

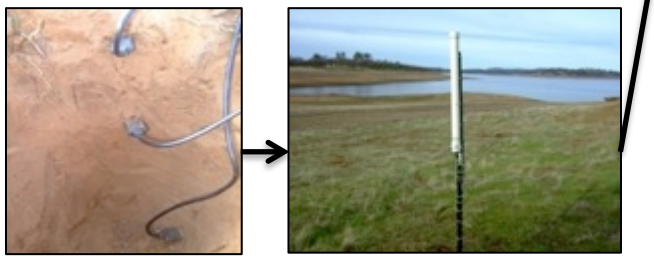
Technology Overview (1)

“Ripple 2D” network architecture design

3 or 4 Decagon EC-5 soil moisture sensors at different depths (typically 5, 20 and 50 cm) define each End Device (ED)







Wirelessly send data to coordinator using custom ‘BETS’ protocol

Send back to USC lab from RPi custom hardware via SMS or 3/4G

Decompress and add to MySQL database, accessible via website

Technology Overview (2)

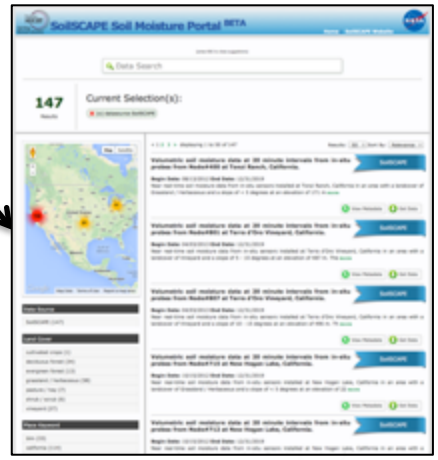
"Ripple 2D" network architecture design

Send data back using custom RPi H/W to USC lab via SMS or 3/4G

Decompress and add to MySQL database, accessible via website Soilscape.usc.edu

SMAP Data System at JPL

Search and discovery portal at ORNL



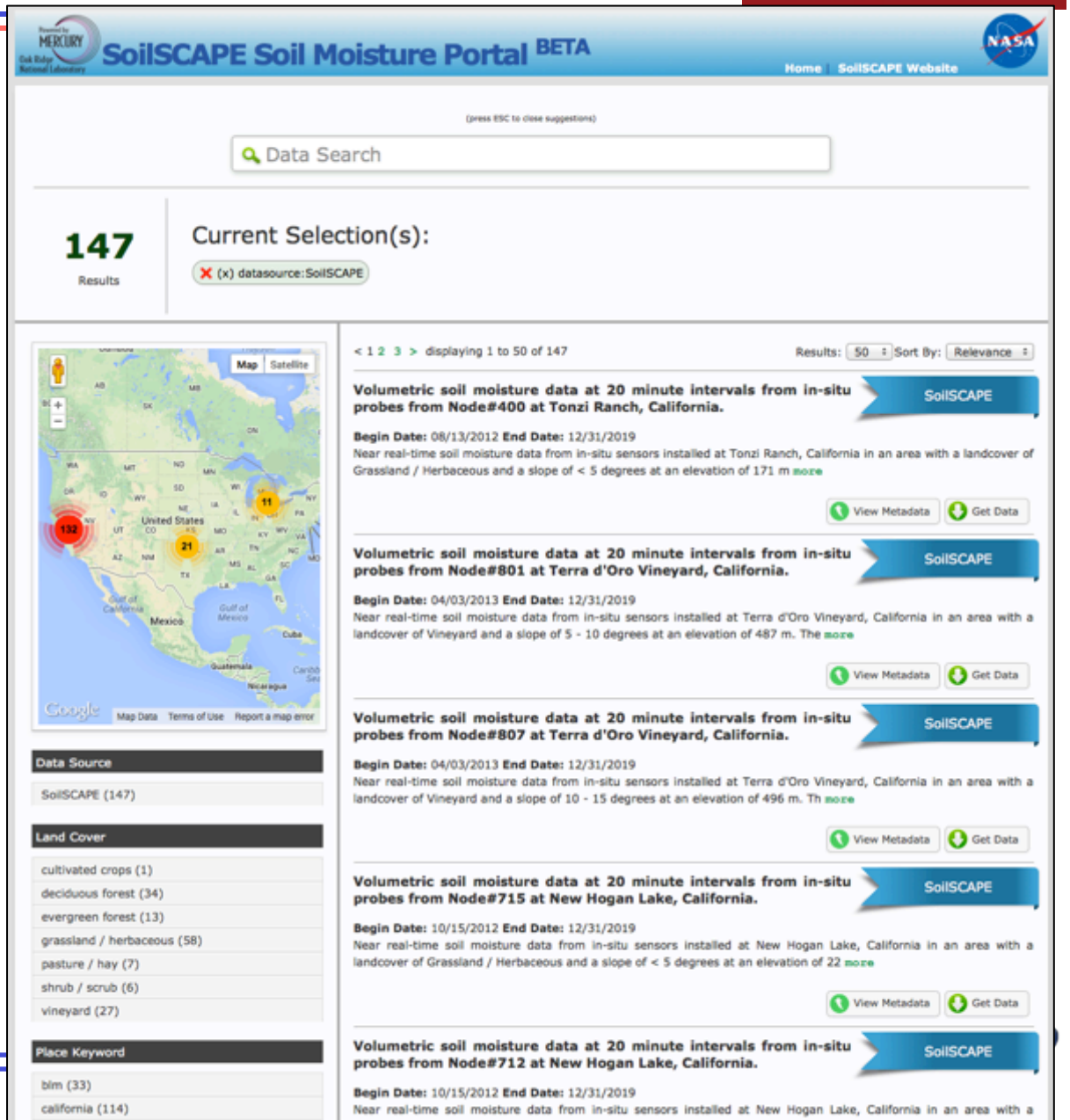
Files containing the last 7 days of data are created every hour for automatic pull by SMAP Cal/Val team at JPL

Technology Overview (3)

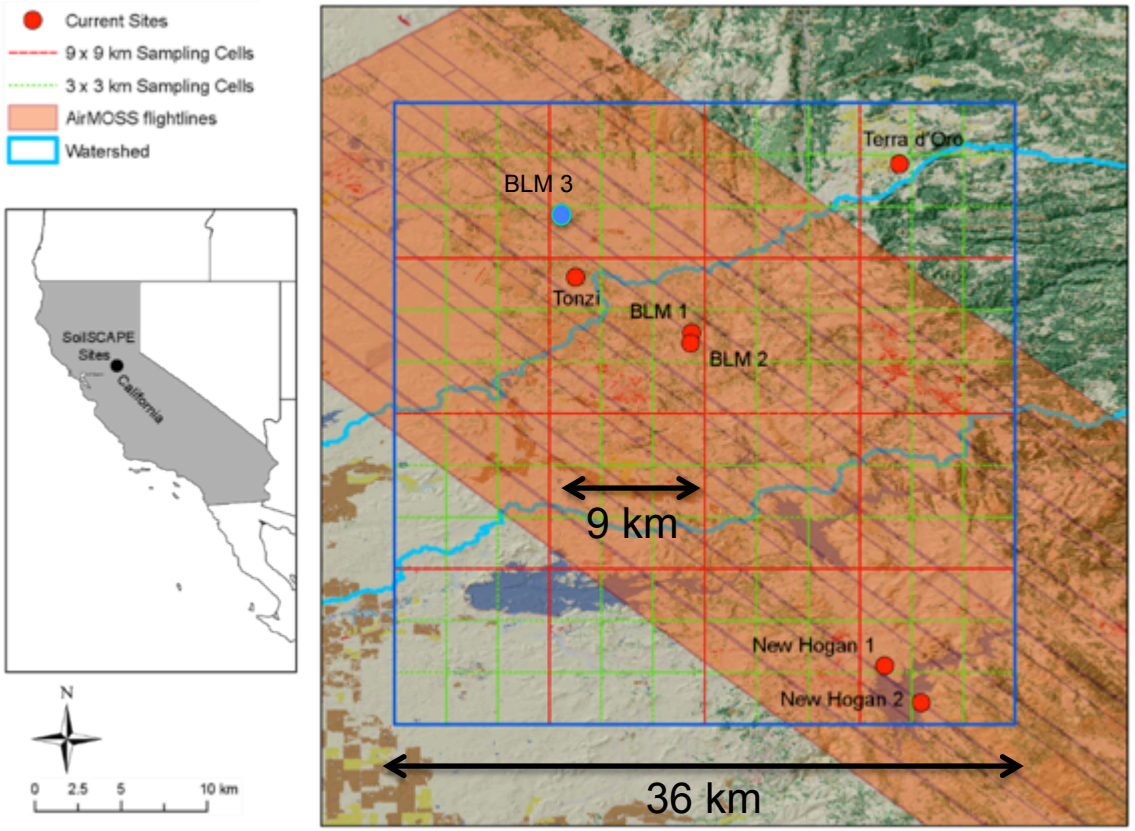
Network Locations

- Central CA “Tonzi Ranch”
  - ❖ 131 nodes
- Canton, OK
  - ❖ 21 nodes
- Ann Arbor, MI (decommissioned)

Screenshot at right is from the SoilSCAPE ORNL portal: http://mercury-ops2.ornl.gov/soilscape/



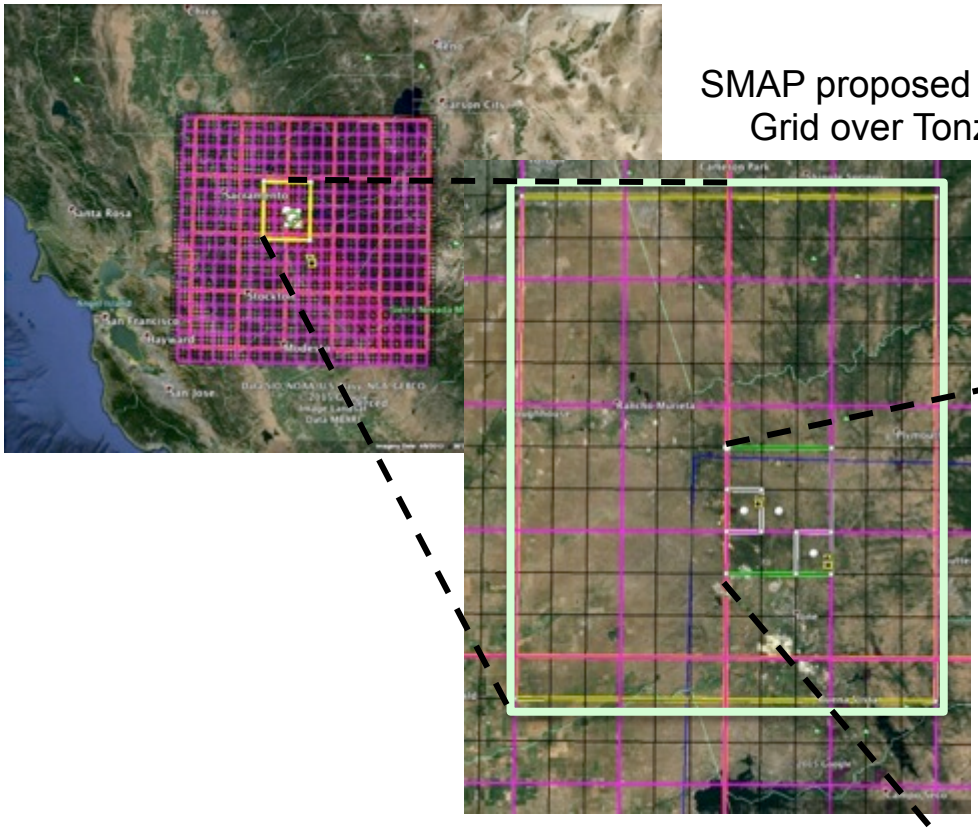
Network node distribution in CA (1)



- 111 nodes operational over 6 sites, 20 nodes permitted and will be installed in July
- Data available in near-real-time from soilscape.usc.edu
- SMAP nested pixel has 3 km, 9 km, and 36 km scales

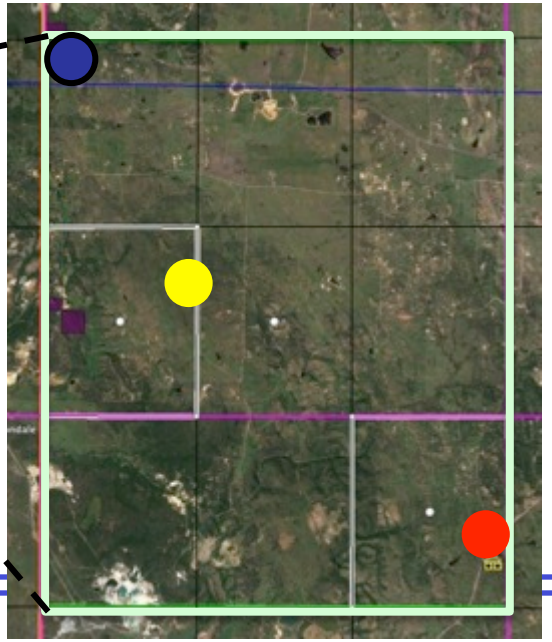
Network node distribution in CA (2)

- Based on request from SMAP Cal/Val team SoilSCAPE will focus on a 9 km validation grid and add nodes accordingly
- New BLM site identified within proposed grid; upon installation in July, SMAP 9 km sampling requirement will be satisfied.



SMAP proposed 36 km Validation
Grid over Tonzi Ranch Area

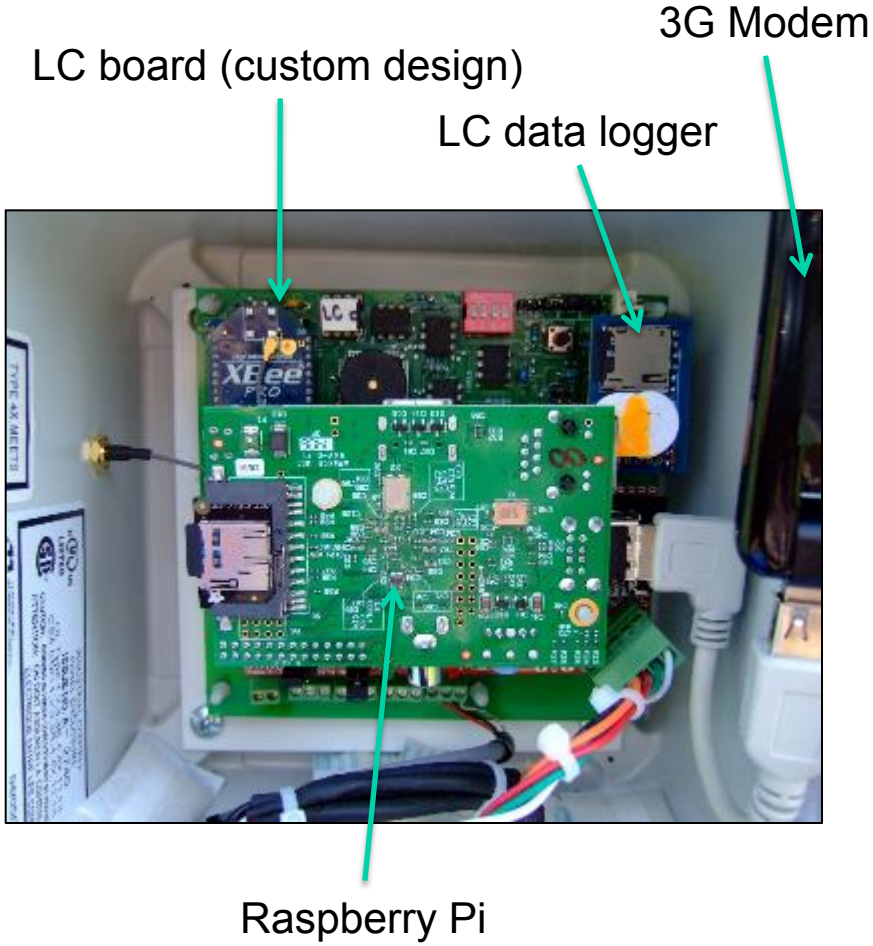
SMAP 9km Validation Focus
(Tonzi Ranch, BLM1 & 2, New BLM3)



Ripple-2 Architecture and Deployment (1)

Ripple-2 Architecture Status

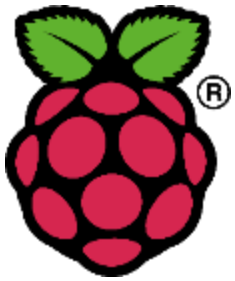
- New local coordinator (LC-RPi-3G) architecture using Raspberry Pi single board Linux computer and 3G modem operating successfully at California sites since April 2014
  - Solution was required to fix various reliability problems such as incompatibility with AT&T hardware upgrades around Tonzi Ranch, CA
  - Also needed for implementing dynamic scheduling of sensor nodes
  - Deployed at all sites in California
- Dual-frequency 2.4 GHz / 900 MHz network operating successfully since April 2014
  - Most nodes have been updated with this version
  - Gives more options for any future sites



Ripple-2 Architecture and Deployment (2)

LC-RPi-3G - Software

- Extra processing power and Linux OS has allowed a number of software improvements to be implemented
  - Data queue – is working well, in particular for sites with poor 3G signal (e.g., Terra d'Oro)
  - Modem configuration requires only a single text file – allows modems to easily be swapped in the field.



debian

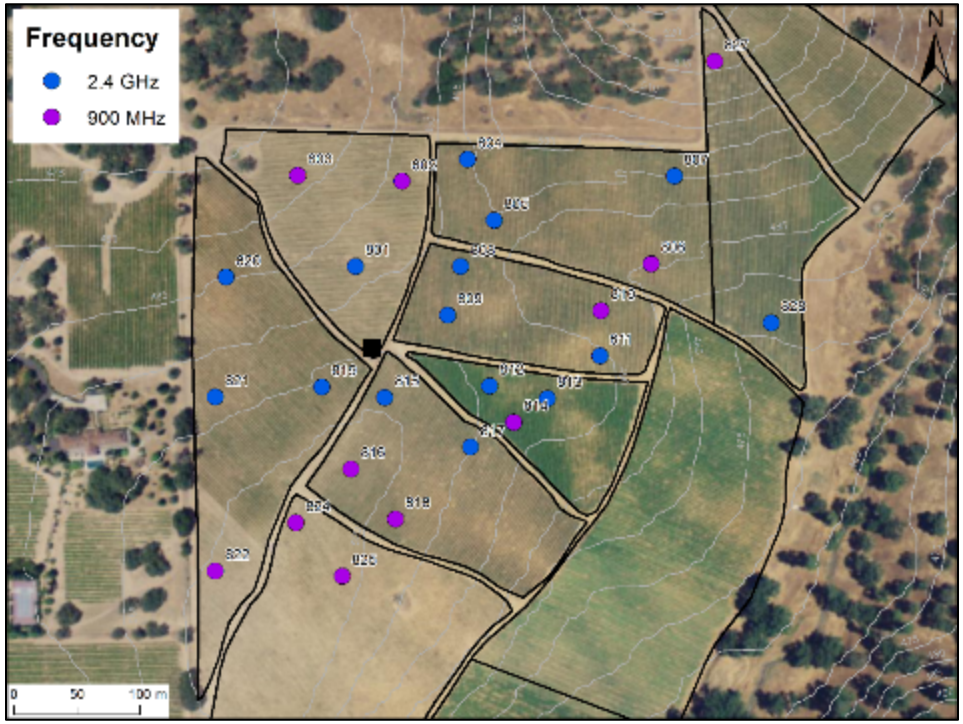
python™

- Have adapted code to send scheduling information to LC
  - Can remotely update software – enables algorithms to be updated without requiring site visits

Ripple-2 Architecture and Deployment (3)

Dual-frequency network

- Has operated successfully at Terra d'Oro vineyard
- Additional nodes planned to be upgraded
- Processing chain works well with receiving data from two base stations at the same site.



Ripple-2 Architecture and Deployment (4)

Current features of the Ripple-2 architecture

- Open and flexible to improvements
  - Dual-frequency network and adaptive scheduling support are examples
  - Inclusion of Raspberry Pi hardware at LC has enhanced flexibility

- Traditional WSNs require 1 infrastructure node (router/repeater, always powered-on) for every 8 sensor nodes in order to cover large areas. With Ripple-2, a single network can support up to 60 EDs and cover an area around 1 km^2 with a single infrastructure node (LC) which is also a sensor node - this is best result so far achieved in WSNs considering the energy and sparsity aspects

- The current software/hardware design has an overhead of less than 1 % compared to 3 - 15 % of traditional WSNs - the lifetime of the batteries is extended by more than 220% (theoretically and empirically demonstrated)

- Homogeneous energy consumption among nodes - we can change all batteries of the nodes in a single visit. Off-the-shelf WSNs do not have this characteristic.

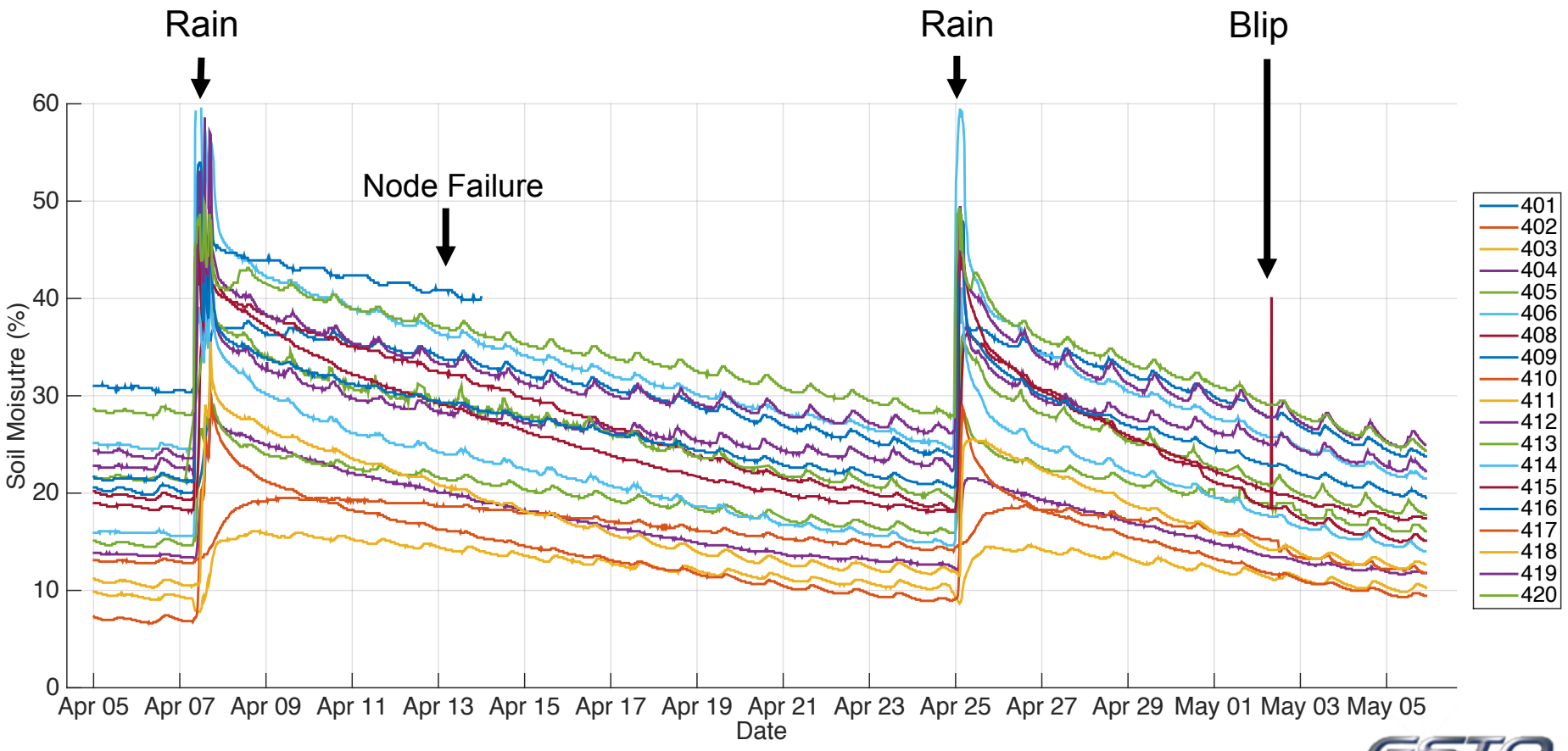
Ripple-2 Architecture and Deployment (5)

Current features of the Ripple-2 architecture

Site	Number of Nodes	Node Density (nodes ha^{-1})	Maximum distance from LC (m)
Tonzi	19	1.45	340
New Hogan 1	14	1.66	257
New Hogan 2	18	1.05	346
Terra d' Oro	27	1.50	317*
BLM 1	17	4.73	207
BLM 2	16	5.09	145

Example Time Series data

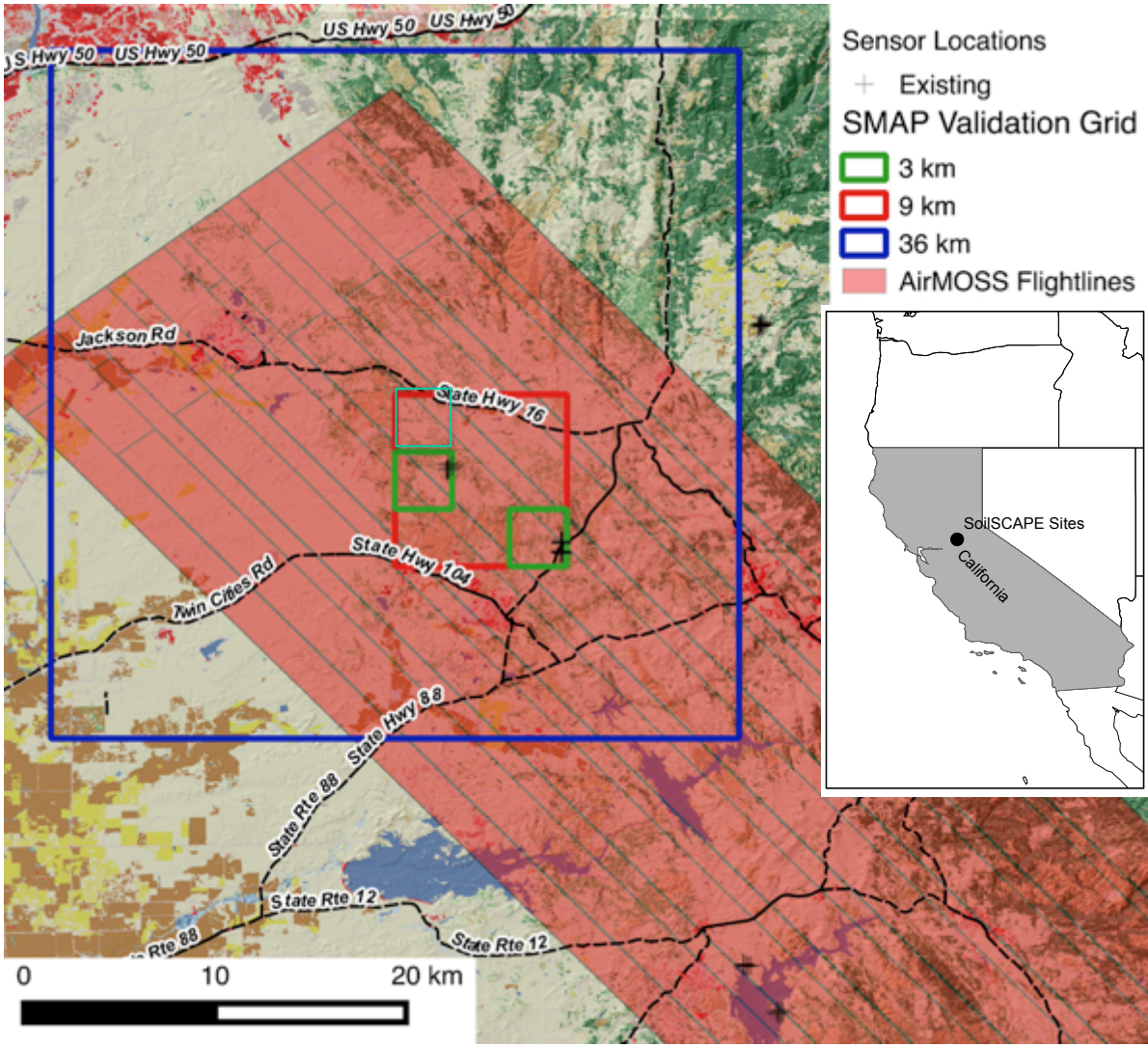
SoilSCAPE Data 04/05/15-05/05/15



Up-Scaling for SMAP Validation (1)

SMAP Validation Grid

- Validation grids for 36 km, 9 km and 3 km soil moisture retrieval
- Focusing on 9 km grid
- Will use 3 ‘clusters’ of nodes within 9 km VG; each cluster has multiple nodes
- Need different approach to upscaling than just averaging: we use ‘random forests’ classification and regression method



Up-Scaling for SMAP Validation (2)

Scaling function overview

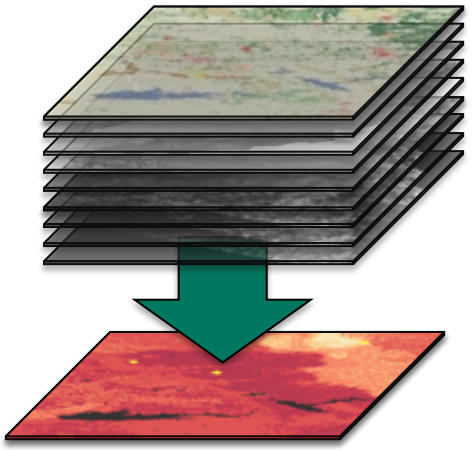
1) Extract and temporally average soil moisture from all available nodes

2) Extract value of data layers (**X**) corresponding to each point

3) Build "Random Forest" regression to predict soil moisture based on **X**

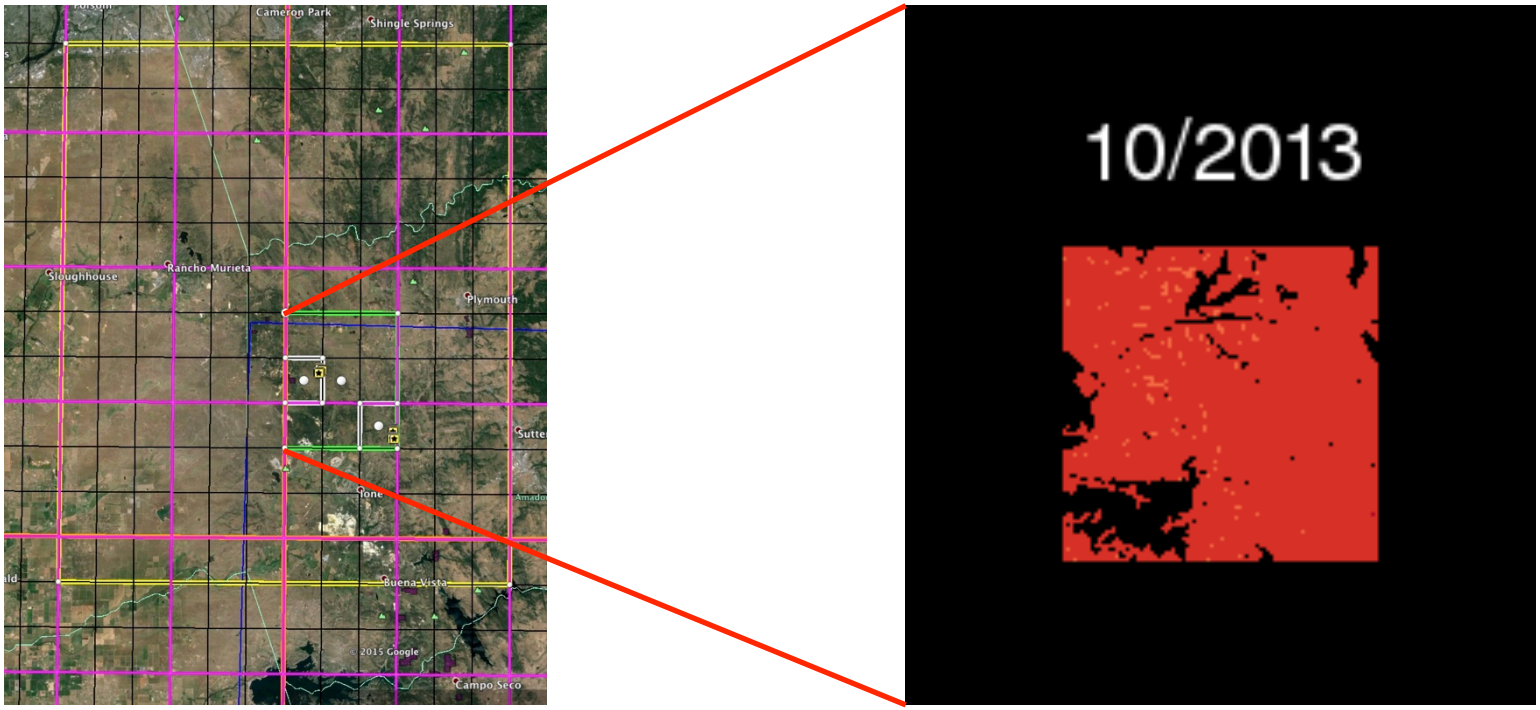
4) Apply "Random Forests" to estimate soil moisture for 100 m pixels within VG

5) Take average soil moisture over all pixels to provide average for VG



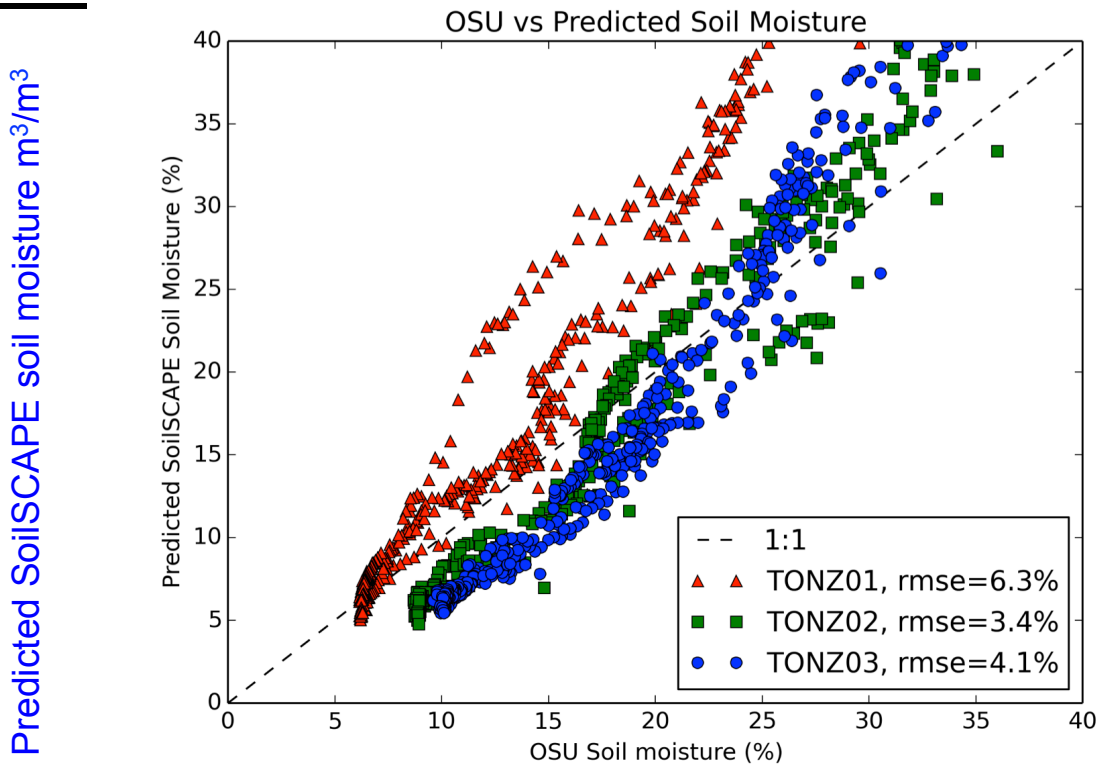
Up-Scaling for SMAP Validation (3)

9km upscaled soil moisture predictions 2013-2014



Up-Scaling for SMAP Validation (4)

Comparison with other sensors at Tonzi Ranch



Reference Data: Oregon State benchmark soil moisture m^3/m^3

- Points represent soil moisture measured by sensors installed at Tonzi ranch by the Oregon State University group compared to predicted soil moisture for co-located 100 m pixels in upscaled results for the same date

Summary

- Networks at Tonzi ranch have demonstrated continuous operation for well over a year
- Have designed, implemented, and demonstrated operation of open architecture
- Scaling analysis for SMAP currently running on Data Server
- Will be able to provide daily upscaled values to SMAP Cal/Val team over HTTP / FTP: still finalizing details
- Network data are already being used by the SMAP cal/val team for validation of 3 km, 9 km, and 36 km products; results not available for public release
- Plan to install a demonstration test-bed for another SMAP core cal/val site at Walnut Gulch, AZ